

**AFRL-RV-PS-  
TR-2014-0172**

**AFRL-RV-PS-  
TR-2014-0172**

## **COMMERCIAL PARTS RADIATION TESTING**

**Craig J. Kief**

**COSMIAC at UNM  
2350 Alamo Avenue SE  
Suite 300  
Albuquerque, NM 87106**

**13 Jan 2015**

**Final Report**

**APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.**



**AIR FORCE RESEARCH LABORATORY  
Space Vehicles Directorate  
3550 Aberdeen Ave SE  
AIR FORCE MATERIEL COMMAND  
KIRTLAND AIR FORCE BASE, NM 87117-5776**

**DTIC COPY**  
**NOTICE AND SIGNATURE PAGE**

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report is the result of contracted fundamental research deemed exempt from public affairs security and policy review in accordance with SAF/AQR memorandum dated 10 Dec 08 and AFRL/CA policy clarification memorandum dated 16 Jan 09. This report is available to the general public, including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (<http://www.dtic.mil>).

AFRL-RV-PS-TR-2014-0172 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNED//  
KEITH AVERY  
Program Manager

//SIGNED//  
JAMES LYKE  
Tech Advisor, Space Electronics Protection Branch

//SIGNED//  
BENJAMIN M. COOK, Lt Col, USAF  
Deputy Chief, Spacecraft Technology Division  
Space Vehicles Directorate

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

# REPORT DOCUMENTATION PAGE

*Form Approved  
OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 13-01-2015			<b>2. REPORT TYPE</b> Final Report		<b>3. DATES COVERED (From - To)</b> 26 Aug 2013 – 22 Nov 2014	
<b>4. TITLE AND SUBTITLE</b> Commercial Parts Radiation Testing					<b>5a. CONTRACT NUMBER</b> FA9453-13-1-0290	<b>5b. GRANT NUMBER</b>
					<b>5c. PROGRAM ELEMENT NUMBER</b> 63401F	<b>5d. PROJECT NUMBER</b> 2181
<b>6. AUTHOR(S)</b> Craig J. Kief					<b>5e. TASK NUMBER</b> PPM00017364	<b>5f. WORK UNIT NUMBER</b> EF120722
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  COSMIAC at UNM 2350 Alamo Avenue SE Suite 300 Albuquerque, NM 87106					<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Air Force Research Laboratory Space Vehicles Directorate 3550 Aberdeen Ave., SE Kirtland AFB, NM 87117-5776					<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> AFRL/RVSE	
					<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b> AFRL-RV-PS-TR-2014-0172	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for Public Release; Distribution is Unlimited						
<b>13. SUPPLEMENTARY NOTES</b>						
<b>14. ABSTRACT</b> The purpose of this research project was to explore a variety of commercially available electronic parts and then to expose these devices to radiation sources to discover what effects various radiation sources had on the systems total ionizing dose capability. The team at the University of New Mexico's COSMIAC Center performed radiation testing on a series of operational amplifiers, microcontrollers and microprocessor. The microprocessors tested include the popular PSOC, MSP430 and Beagle Bone Black platforms. While the MSP430 and Beagle Bone Black had excellent results, the PSOC proved unreliable for space applications.						
<b>15. SUBJECT TERMS</b> Modular propulsion; environmentally safe fuel, SPA, Navigation, CCS, HPGA						
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> Keith Avery	
a. REPORT uncl	b. ABSTRACT uncl	c. THIS PAGE uncl	Unlimited	18	<b>19b. TELEPHONE NUMBER (include area code)</b>	

(This page intentionally left blank)

Approved for Public Release; distribution is unlimited.

## Table of Contents

1. Summary .....	1
2. Introduction.....	1
3. Methods, Assumptions, and Procedures .....	3
4. Results and Discussion .....	7
5. Conclusions .....	7
Appendix: Publications and Presentations .....	8
List of Abbreviations, Symbols, and Acronyms .....	9

Approved for Public Release; distribution is unlimited.

## **List of Figures**

Figure 1. Trailblazer Satellite .....	1
Figure 2. ORS Squared.....	2
Figure 3. Cypress PSOC.....	3
Figure 4. Beagle Bone Black.....	4
Figure 5. MSP430 .....	4
Figure 6. BBB Supply Current.....	5
Figure 7. MSP430 Supply Current .....	6

Approved for Public Release; distribution is unlimited

## **Acknowledgement**

This material is based on research sponsored by Air Force Research Laboratory or the U.S. Government under agreement number FA9453-13-1-0290. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon.

## **Disclaimer**

The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Air Force Research Laboratory or the U.S. Government.

(This page intentionally left blank)

Approved for Public Release; distribution is unlimited

## **1. Summary**

The University of New Mexico (UNM) proposed to create a test platform for performing Total Ionizing Dose (TID) testing. The project was to be led by the researchers at the Configurable Space Microsystems Innovations and Applications Center (COSMIAC) at UNM. The Principal Investigator was Mr. Craig Kief.

COSMIAC developed two CubeSats for delivery to the National Aeronautics and Space Administration (NASA) in 2013 and 2014. This gives the team the background to be able to understand the advantages and costs related to flying radiation hardened parts.

## **2. Introduction**

The current trend in nanosatellites is the use of a standard called the CubeSat. The CubeSat form factor is described with the use of "U" for units. A 1U is 10cm x 10cm x 10cm. A 6U is 10cm x 20cm x 30cm. UNM completed the design, build and launch of a 1U CubeSat called Trailblazer (see Figure 1) that was launched in November of 2013 upon an Operationally Responsive Space (ORS) mission. In addition, COSMIAC is working to complete a 6U spacecraft called ORS Squared for launch in late 2014. This spacecraft is shown in Figure 2. These small spacecraft provide an optimal solution for testing electronics in flight. However, before choosing one over the other, it is important to have some initial radiation test results.



Figure 1. Trailblazer Satellite

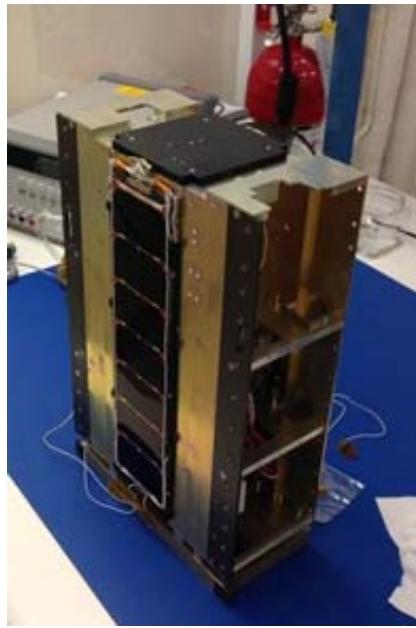


Figure 2. ORS Squared

The team said that they would use the provided funds to complete three major goals:

- Purchase a range of different commercial microcontroller and microprocessor equipment. The team would develop a list of the most promising commercial parts that might be utilized to create control systems and modules for CubeSat missions. These parts will be chosen based on knowledge of their proposed use in flight missions. The parts will include microprocessors, microcontrollers and memory modules. In addition, Field Programmable Gate Arrays (FPGAs) will also be chosen.
- Develop test frames and platforms for use in testing the parts in a Total Ionizing Dose environment. Each part needs to be mounted onto a platform that will allow electrical and physical interconnection to them during the test phase. The way the Total Ionizing Dose (TID) testing occurs is for the parts to be running in a routine mode and then to be exposed to the radiation source. As the total dose continues to increase, there should be a way to tell when the part begins to fail. As such, the test regimen needs to include a way to write to the device as well as reading from the device. The results should be stored in an easily exportable format similar to an Excel spreadsheet. The time should also be recorded into the test results so that the precise time of failure can be documented. It is from this precise time that it is possible to tell failure times and predict flight reliability.
- Publish results on website. The true power of these results will be to the small satellite community. The results will be added to the other analysis results that are currently on the COSMIAC website and presented at conferences.

### **3. Methods, Assumptions, and Procedures**

One of the most promising microcontroller systems the team looked at is the Beagle Bone Black (BBB) system. This processing board can run an entire Linux operating system. Based on this research, COSMIAC created plans to fly this system on UNM's second satellite to be launched in 2014. The reason this processor was chosen as the main controller on UNM's second satellite is in part due to the radiation results obtained from this funded activity.

Progress has been made on these goals and the details are provided below.

Goal 1: Three microcontroller systems were chosen for testing. The three microcontroller processors with their associated test platforms that were chosen for testing are the Cypress Corporation's Programmable System-on-Chip (PSOC), the Beagle Bone Black and the MSP430. A significant amount of Operational Amplifiers (OP AMPS) were also chosen for testing due to their ability to be used in future missions.

The PSOC (shown in Figure 3) failed immediately in the radiation environment. Based on these initial results, no further testing was accomplished on PSOC processors and the manufacturer was informed of these results. Based on the feedback that COSMIAC provided to this vendor, they have begun looking into different testing and design parameters that might improve radiation resistance.



Figure 3. Cypress PSOC

The parts that proved most reasonable for future testing were the Beagle Bone Black (shown in Figure 4) and the MSP430 (shown in Figure 5).

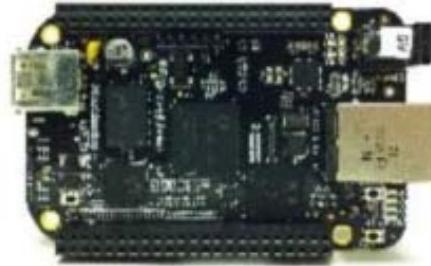


Figure 4. Beagle Bone Black



Figure 5. MSP430

Two Beagle Bone units were tested in Cobalt-60 source on Kirtland Air Force Base at a dose rate of 53 radians per second. The test software was designed primarily to access the memory (or file system) residing on the embedded Multi-Media Controller (eMMC) or Secure Digital (SD) card. The test also exercised the two wire port and Ethernet interface. For initial irradiation of the first test unit, no shielding was used. The unit quit operating after 17.9 kilo-radians, due to loss of functionality in the SD card containing the operating code. With SD card shielded, the unit continued to function until 23.3 kilo-radians. The second test unit was irradiated under the same test conditions with SD card shielded. It failed at 17.3 kilo-radians. Another unit was

also tested without failure at 15 kilo-radians. All unit were subjected to an anneal at 100 degree Celsius for 168 hours. Unit one recovered full operation and unit three remained operational after the test. Supply current was captured in Figure 6.

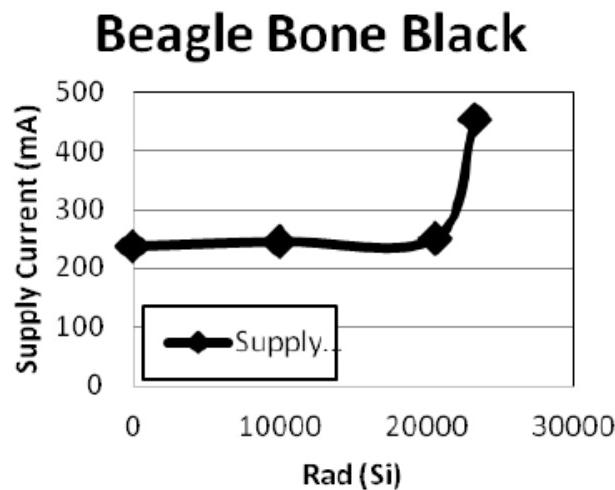


Figure 6. BBB Supply Current

Two MSP430 units were subjected to high dose rate irradiation at the Cobalt-60 source with a collimator used to shield everything on the development board except the MSP430. Dosage values were determined with the RadCal Corporation's 2026 dosimeter with a 0.18 cubic centimeter ionization chamber for Cobalt-60 and a 180 cubic centimeter ionization chamber for the Cesium-137. RadCal Corporation's 2026 calibration is traceable to National Institutes of Standards and Technology (NIST) standards. The MSP430 microcontroller was operating continuously throughout the test. The test software was designed primarily to access the memory, communication, and computational circuitry of the MSP430. Data was logged every 10 seconds during the test. The Co-60 source was dropped every 10 kilo-radians to permit the supply current to be logged without any contributions from ionization currents.

MSP430 test article one failed at 244 kilo-radians, and test article 2 failed at 248 kilo-radians. The supply currents for each device are shown in Figure 7 as a function of total dose. The currents showed relatively minor (5mA) fluctuations up to 200 kilo-radians, but dropped precipitously between 200 kilo-radians and failure. Functionality could not be recovered by annealing at 100 degrees Celsius for 168 hours.

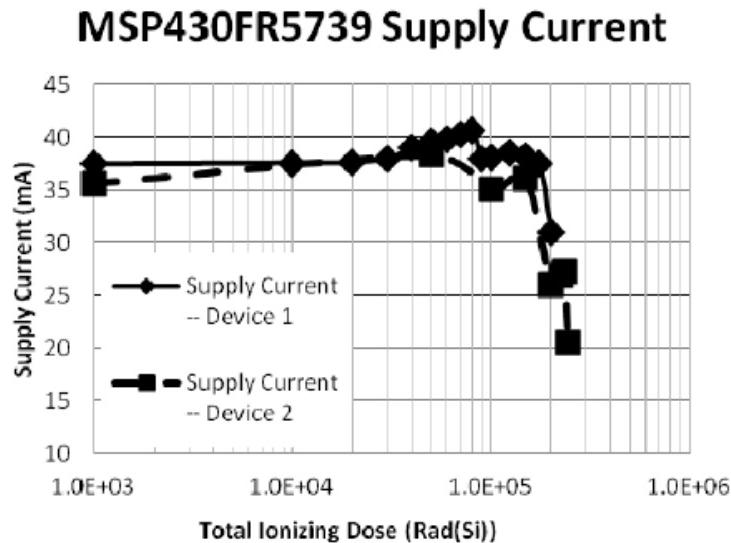


Figure 7. MSP430 Supply Current

A third test article (MSP430) was irradiated in the Cesium-137 source at 10 milliradians per second. The device logged data every 10 minutes and was removed from the source after 250 days of continuous operation and a total accumulated dose of 212.8 kilo-radians. The device remained fully functional. The test was halted due to unreliable serial to USB conversion in the emulation chip incorporated on the evaluation board. The emulation chip incorporates flash memory and although it was shielded during the Cesium-137 irradiation, it still received 21 kilo-radians of dose, which is a typical failure level for embedded flash. The MSP430 has proven to be quite robust in its TID response and is under consideration for several CubeSat missions.

Total ionizing dose exposures at high and low dose rates were performed on eight types of commercial OP AMPS to determine their failure thresholds. The devices chosen were fabricated with either Complementary Metal–Oxide–Semiconductor (CMOS) or Junction Field Effect Transistors (JFET) technologies. No evidence of Enhanced Low Dose Rate Sensitivity (ELDRS) effects were identified in any of the CMOS OP AMPS. Radiation inclusive macro-models were developed to facilitate simulation of circuit designs incorporating the devices investigated.

Goal 2: A separate test frame and software to support testing had to be developed for each of the three tested platforms and the operational amplifiers. Often, the testing software could be modified and reused. This reduced development time so more time could be spent on actual testing. Each of these three platforms was tested in the various radiation sources on Kirtland Air Force Base. The Beagle Bone and MSP430

performed exceptionally well and are now being considered for space flight modules. The PSOC device performed poorly and was not considered for further testing or use.

Goal 3: Test results are still being analyzed so it could take another few months before the website is updated. Two papers have been submitted to the Hardened Electronics and Radiation Technology (HEART) conference and the papers are included as Attachments one and two of this report. Test results have already been provided to scientists in the community in advance of the formal final report. Further discussion is ongoing about potential additional radiation testing (total dose and single event). There were approximately 100 CubeSats launched in the past year so dissemination of this information to the broadest audience is critical.

#### **4. Results and Discussion**

The MSP430 boards as well as the Beagle Bone Black units provided best protection for total dose radiation. No assumptions can be made about upset levels related to flight at Low Earth Orbit (LEO) however; the recent advances in die size provide a certain amount of single event protection that should be investigated. For actual flight beyond LEO, beam testing would have to be performed. This type of testing is not available in Albuquerque. This type of work could also be coordinated with NASA collaborators as they have the same constraints associated with the use of rad hard processors for longer duration space missions.

#### **5. Conclusions**

As shown in the published papers, certain processors and operational amplifiers that are very inexpensive have provided the robust capabilities needed to use in certain space applications. The team at UNM/COSMIAC is now working with these processors to help to develop future applications and missions where they would be utilized and are creating proposals to support future beam testing for analysis on single event effect mitigation.

## Appendix: Publications and Presentations

Vera, Alonso, et al., "Total Ionizing Dose Effects on Commercial Electronics for Cube Sats in Low Earth Orbits," *Hardened Electronics and Radiation Technology (HEART) Conference*, 21-24 April 2015.

Alexander, David, et al., "Total Ionizing Dose Effects on Commercial CMOS and JFET Op Amps," *Hardened Electronics and Radiation Technology (HEART) Conference*, 21-24 April 2015.

## **List of Abbreviations, Symbols and Acronyms**

AFRL	Air Force Research Laboratory
BBB	Beagle Bone Black
CMOS	Complementary Metal–Oxide–Semiconductor
COSMIAC	Configurable Space Microsystems Innovations and Applications Center
ELDRS	Enhanced Low Dose Rate Sensitivity
eMMC	embedded Multi-Media Controller
FPGA	Field Programmable Gate Array
HEART	Hardened Electronics and Radiation Technology
JFET	Junction Field Effect Transistors
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
OP AMPS	Operational Amplifiers
ORS	Operationally Responsive Space
PSOC	Programmable System-on-Chip
SD	Secure Digital
TID	Total Ionizing Dose
UNM	University of New Mexico

## DISTRIBUTION LIST

DTIC/OCP  
8725 John J. Kingman Rd, Suite 0944  
Ft Belvoir, VA 22060-6218                    1 cy

AFRL/RVIL  
Kirtland AFB, NM 87117-5776                2 cys

Official Record Copy  
AFRL/RVSE/Keith Avery                        1 cy